

PHILOSOPHICAL TRANSACTIONS.

I. THE BAKERIAN LECTURE.—*Experimental Researches in Electricity.—Twenty-fourth Series.* By MICHAEL FARADAY, Esq., D.C.L., F.R.S., Fullerian Prof. Chem. Royal Institution, Foreign Associate of the Acad. Sciences, Paris, Ord. Boruss. Pour le Mérite, Eq., Memb. Royal and Imp. Acadd. of Sciences, Petersburgh, Florence, Copenhagen, Berlin, Göttingen, Modena, Stockholm, Munich, Bruxelles, Vienna, Bologna, &c. &c.

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§ 30. *On the possible relation of Gravity to Electricity.*

2702. THE long and constant persuasion that all the forces of nature are mutually dependent, having one common origin, or rather being different manifestations of one fundamental power (2146.), has made me often think upon the possibility of establishing, by experiment, a connection between gravity and electricity, and so introducing the former into the group, the chain of which, including also magnetism, chemical force and heat, binds so many and such varied exhibitions of force together by common relations. Though the researches I have made with this object in view have produced only negative results, yet I think a short statement of the matter, as it has presented itself to my mind, and of the result of the experiments, which offering at first much to encourage, were only reduced to their true value by most careful searchings after sources of error, may be useful, both as a general statement of the problem, and as awakening the minds of others to its consideration.

2703. In searching for some principle on which an experimental inquiry after the identification or relation of the two forces could be founded, it seemed that if such a relation existed, there must be something in gravity which would correspond to the dual or antithetical nature of the forms of force in electricity and magnetism. To my mind it appeared possible that the ceding to the force or the approach of gravitating bodies on the one hand, and the effectual reversion of the force or separation of the bodies on the other, might present the points of correspondence; quiescence

(as to motion) being the neutral condition. The final unchangeability of gravity did not seem affected by such an assumption; for the acting bodies when at rest would ever have the same relation to each other, and it would only be at the times of motion to and fro that any results related to electricity could be expected. Such results, if possible, could only be exceedingly small; but, *if possible*, i. e. if true, no terms could exaggerate the value of the relation they would establish.

2704. The thought on which the experiments were founded was, that, as two bodies moved towards each other by the force of gravity, currents of electricity might be developed either in them or in the surrounding matter in one direction; and that as they were by extra force moved from each other against the power of gravitation, the opposite currents might be produced. Also, that these currents would have relation to the line of approach and recession, and not to space generally, so that two bodies approaching would have currents in the opposite direction as to space generally, but the same as to the direction of their motion along the line joining them. It will be unnecessary to go further into the suppositions which arose concerning these points, or regarding the effect of forced motions either coinciding with, or across the direction of the earth's gravitation, and many other matters, than to say that, as the effect looked for was exceedingly small, so no hope was entertained of any result except by means of the gravitation of the earth. The earth was therefore made to be the one body, and the indicating mass of matter to be experimented with the other.

2705. First of all, a body, which was to be allowed to fall, was surrounded by a helix, and then its effect in falling sought for. Now a body may either fall with a helix or through a helix. Covered copper wire, to the amount of 350 feet in length, was made into a hollow cylindrical helix, about 4 inches long, its internal diameter being 1 inch and its external diameter 2 inches. It was attached to a line running upon an easy pulley, so that it could be raised 36 feet, and then allowed to fall with an accelerated velocity on to a very soft cushion, its axis remaining vertical the whole time. Long covered wires were made fast to its two extremities, and these being twisted round each other, were attached to a very delicate galvanometer, placed about 50 feet aside from the line of fall, and on a level midway with its course. The accuracy of the connection and the direction of the set of the needle, were then both ascertained by the introduction of a feeble thermo-electric combination into the current. Such a helix, either in rising or falling, can produce no deviation at the galvanometer by any current due to the magnetism of the earth; for as it remains parallel to itself during the fall, so the lines of equal magnetic force, which being parallel to the dip, are intersected by the wire convolutions of the descending helix, are cut with an equal velocity on both sides of the helix, and consequently no effect of magneto-electric induction is produced. Neither in rising nor in falling did this helix present any trace of action at the galvanometer; whether the connection with the galvanometer was continued the whole time, or whether it was cut off just before the

diminution or cessation of motion either way, or whether the rising and the falling were made to occur isochronously with the times of vibration of the galvanometer needle. So, though no effect of gravity appeared in the helix itself, still no source of error appeared to arise in this mode of using it.

2706. A solid cylinder of copper, three-fourths of an inch in diameter and 7 inches in length, was now introduced into the helix and carefully fastened in it, being bound round with a cloth so as not to move, and this compound arrangement was allowed to fall as before (2705.). It gave very minute but remarkably regular indications of a current at the galvanometer; and the probability of these being related to gravity appeared the greater, when it was found that on raising the helix or core, similar indications of contrary currents appeared. It was some time before I was able to refer these currents to their true cause, but at last I traced them to the action of a part of the connecting wires proceeding from the helix to the galvanometer. The two wires had been regularly twisted together, but the effect of many falls had opened a part near the middle distance into a sort of loop, so that the wires, instead of being tightly twisted together like the strands of a rope, were separate for 3 feet, as if the strands were open. In falling, this loop opened out more or less, but always in the same manner; and the consequence was that the part of it representing the transverse opening, which was furthest from the galvanometer, travelled over a larger space than the corresponding part nearest the galvanometer. Now had they travelled through equal spaces, the effect of the magnetic lines of force of the earth upon them would have been equal, and no effect at the galvanometer would have been produced; as it was, currents in opposite directions, but of unequal amounts of force, tended to be produced, and a current equal to the difference actually appeared. Such a case is described in my earliest researches on terrestrial magno-electro induction (171.). It is evident that the current should appear in the reverse direction, as the helix and wires are raised in the air, and thus arose the reverse effect described above. Therefore no positive or favourable evidence was supplied in favour of the original assumption by this use of a copper core in the helix.

2707. The copper was selected as a heavy body and an excellent conductor of electricity. On its dismissal, a bismuth cylinder of equal size was employed to replace it as a substance eminently diamagnetic, and a bad conductor amongst metals. Uncertain evidence arose; but by close attention, first to one point and then to another, all the indications disappeared, and then the rising or falling of the bismuth produced no effect on the galvanometer.

2708. An *iron* cylinder was also employed as a magnetic metal, but when made perfectly secure, so as to prevent any motion relative to the helix, it was equally indifferent with the copper and bismuth (2706. 2707.).

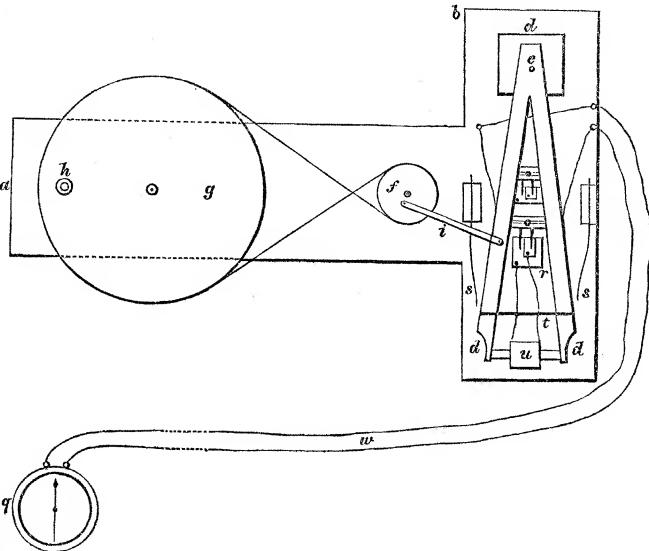
2709. Cylinders of glass and shell-lac were employed as non-conducting substances, but without effect.

2710. In other experiments the helix was *fixed*, and the different substances in the

form of cylinders, three-fourths of an inch in diameter and 24 inches long, were dropped through it, or else raised through it with an accelerated velocity; but in neither case was any effect produced. Rods of copper, bismuth, glass, shell-lac and sulphur were employed. Occasionally these rods were made to rotate rapidly before and during their fall; and many other conditions were devised and carried into effect, but always with negative results, when sources of error were avoided or accounted for.

2711. On further consideration of the original assumption, namely, a relation between the forces, and of the effects that might be looked for consequent upon a condition of tension in and around the particles of the body, which, as we know, are at the same moment the residence of both gravitating and electric forces, and are subject to the gravitation of the earth, it seemed probable that the stopping of the up and down motion (2703. 2704.) in the line of gravity would produce contrary effects to the coming on of the motion, and that, whether the stopping was sudden or gradual; also that a motion downward quicker than that which gravity could communicate, would give more effect than the gravity result by itself, and that a corresponding increase in the velocity upwards would be proportionally effectual. In such case a machine which could give a rapid alternating up and down motion, might be very useful in producing many minute units of inductive action in a small space and moderate time; for then, by proper commutators, the accelerated and retarded parts of each half-vibration could be separated and recombined into one consistent current, and this current could be sent through the galvanometer during the time its needle was swinging in one direction, and afterwards reversed for the time of a swing in the other direction; and so on alternately until the effect had become sensible, if any were produced by the assumed cause.

2712. The machine which I had made for this purpose is that described in the last Series of these Researches (2643.), the electro-magnet, the experimental core and the rod which carried them being removed:—*a, b, c* frame-board; *d, d, d* wooden lever, of which *e* is the axis; *f* the crank-wheel, and *g* the great wheel with its handle *h*; *i* the bar connecting the crank-wheel and lever; *q* the galvanometer; *r* the commutator; *w*, connecting wires; *s, s* springs of brass or copper; *t* a copper rod connecting the two arms of the lever to give strength; *u* the hollow helix fixed, or moveable at pleasure. The plan is to a scale of one-fifteenth. Being on a



moveable frame, it could be placed in any position. The cylinder of metal or other substance to be submitted to its action, was $5\frac{1}{2}$ inches long and three-fourths of an inch in diameter, and was firmly held between the ends d, d of the lever arms. The extent of the alternating motion was 3 inches. A hollow cylindrical helix $u, 2\frac{1}{2}$ inches in length, and of such internal diameter that the cylinders could complete their rapid journeys to and fro within it without any danger of striking against its sides, was constructed, containing 516 feet of covered copper wire; this cylinder could be either fixed immovably or attached firmly to the cylinder under experiment so as to move with it. The wires from this helix passed to the commutators and from them to the galvanometer. Part of the momentum of this machine was taken up by springs s, s (2648.), and converted into the contrary motion; but so much remained undisposed of thus, that great care was required in fixing and strutting to render the action of the whole very steady, or else derangement quickly occurred at the cylinder and helix, and electro-currents were frequently produced.

2713. The employment of cylinders of iron, copper and other substances in this machine, was competent to produce electro-currents in various ways. Thus, iron might produce magneto-electric currents consequent upon its polar condition under the influence of the earth; these it would be easy to detect and separate by the use of adjusted magnets, which should neutralize or reverse the lines of magnetic force passing through the iron. Currents like those induced in copper cylinders and good conductors (2663. 2684.), might be produced by the earth's action; but as the lines of gravitating force and of terrestrial magnetic force are inclined to each other, these might be separated by position; and it appeared that there was no source of error that might not by care be eliminated. I will not occupy time by describing how this long lesson of care was learned, but pass at once to the chief results.

2714. The copper cylinder (2712.) was placed in the machine, and the helix fixed immovably around it, the whole being in such a position that the cylinder should be vertical, and move up and down parallel to the line of gravitating force within the helix. However rapidly the machine was worked, or whatever the position of the commutator, there was no result at the galvanometer. Cylinders of bismuth, glass, sulphur, gutta percha, &c., were also employed, but with the same negative conclusion.

2715. Then the helix was taken from its fixed support and fastened on to the copper cylinder so as to move with it, and now very regular and comparatively large effects were produced. After a while, however, these were traced to causes other than gravity, and of the following kind. The helix was fixed at one end of a lever, at a point 22 inches from its axis, and being 2 inches in diameter its wires on one side were only 21 inches, and on the other side 23 inches from this axis. Hence, in vibrating these parts travelled with velocities and through spaces which are as 21 : 23. When therefore their paths were across the lines of magnetic force of the earth, electro-currents tended to form in these different parts proportionate in amount or

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strength to these numbers; and the differences of these currents being continually gathered up by the commutators, were made sensible at the galvanometer. This was rendered manifest by placing the machine so, that though the plane of vibration was still vertical, the place of the helix was just under the centre of motion, and the central line of the helix therefore, instead of being vertical, was horizontal. Now the convolutions of the helix cut the lines of magnetic force in the most favourable manner; and the consequence was that the commutators were not required, for a single motion of the helix in one direction was sufficient to show at the galvanometer the magneto-electric currents induced. If, on the contrary, the plane of motion was made horizontal, then no current was produced by any amount of motion; for though the helix was as horizontal as, and not sensibly more so than before, yet the parts of the convolutions which intersected the magnetic lines of force (being the upper and the lower parts) now moved with exactly equal velocity, and no differential result was produced.

2716. The former small result (2715.) was therefore probably dependent upon an effect of this kind; and this was confirmed by placing the machine in such a position that the axis of the moving copper cylinder and helix should in its medium position be parallel to the line of the dip, and then no effect was produced. Other bodies in the same position were equally unable to produce any effect.

2717. Here end my trials for the present. The results are negative. They do not shake my strong feeling of the existence of a relation between gravity and electricity, though they give no proof that such a relation exists.

*Royal Institution,
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